Sirex Science Panel

Report[1]

December 13 & 14, 2006
Indianapolis, IN

Members

Robin Bedding – CSIRO Australia
Angus Carnegie – NSW DPI, Australia
Peter de Groot, CFS
Kevin Dodds – USDA-FS-FHP
Rene Germain - SUNY-ESF
Fred Hain – NC State
Dennis Haugen – USDA-FS-FHP
Edson T. Iede, Embrapa Florestas, Brazil
Douglas Allen – SUNY-ESF
Dave Lance – USDA-APHIS-PPQ
Vic Mastro (chair) – USDA-APHIS-PPQ
Richard Reardon – USDA-FS
Don Rogers – NC Div. of Forest Resources
Nathan Schiff – USDA-FS
Jim Tumlinson – Penn State
Dave Williams – USDA-APHIS-PPQ
Bernard Slippers – Univ. of Petoria, S. Africa

[1] Issued March 23, 2007

Sirex Science Panel Report
Indianapolis, IN
December 13 & 14, 2006

A *Sirex* Science Panel meeting was held December 13-14, 2006 in Indianapolis, IN to revisit recommendations made in the first SSP report, address specific questions posed by the Management Team, and review new information on *Sirex* and its distribution. The meeting opened with presentations about survey and research activities conducted in 2006.

Reports to the Panel

Shahla Werner – Pennsylvania Department of Conservation and Natural Resouces – In PA, they surveyed the northern portion of the state for *Sirex* to complete the “circle” around Oswego. Various grids were trapped by PPQ (100-some), Pennsylvania Department of Agriculture (51), PA Department of Conservation and Natural Resources (45) and the U.S. Forest Service. No trapping was conducted if there was no suitable pine habitat in the grid. They captured single adult *S. noctilio* females at two different sites. They also caught 135 or so other siricids. They used 8- or 12-funnel Lindgren traps that were elevated so that the collection cups were not on the ground, but traps typically weren’t as high as specified. Lures were changed twice, July and August. Their program was not ideal, but it was the best they could do with available funding.

The two positive traps were located at Hill’s Creek State Park, Tioga Co., 7/24/06, where one female was trapped. There are two unmanaged red pine stands in the park, but neither showed signs of *Sirex*. Six trees were cut for further sampling purposes. The second find was in a red pine stand in Bradford Co. Pennsylvania is considering regulating firewood; if they do, this may also include softwood. If this action is taken, it could help with artificial movement of *Sirex* and other exotics.

Leon Bunce – APHIS-PPQ-ER – Reported on the 2006 delimiting, port of entry, high risk, and CAPS surveys. The delimiting survey used 2000 traps baited with 70:30 alpha:beta pinene. The area trapped included NY, VT, and PA, in a 150-mi. radius from Oswego, NY. Almost 2000 traps were used in NY at 1 trap/25 sq. mi. In some areas, the grid was a bit more dense. In Vermont, they also used 1 trap/25 sq. mi. *Sirex noctilio* were found in trap checks from 7/3 to 10/11/06. A total of 58 were caught; all but 3 were females. These results give 20 new county records in NY and 2 in PA. In NY, when a trap caught a *Sirex*, that trap was then moved to a new trap site. This confounds looking at the seasonality of capture a bit. Port-of-entry survey included 50 sites, looking at SWPM from *Sirex*-infested countries. *Sirex* had, in the past, been a non-actionable pest. There was a discussion about the ability of ISIS to handle non-target data. Leon said he would check on this.

Lynn Evans-Goldner – APHIS-PPQ, Riverdale, MD – Reported survey results for APHIS-PPQ – Western Region. Trapping was conducted as part of either CAPS, EEB, and/or Forest Service early detection program in Arizona, California, Colorado, Idaho, Kansas, Oklahoma, Oregon, Louisiana, Missouri, Monta, Nevada, North Dakota, South Dakota, Texas, Utah, Washington, and Wyoming. In addition, some trapping was carried out in almost every state through various programs (CAPS, FS, etc.). All results from 2006 were negative.

Kevin Dodds – He presented the update on the U.S. Forest Service support activities for Noel Schneeberger, who was late due to plane troubles. The FS funded Northeastern area states to run surveys in high-risk sites. This supplemented the delimitation effort. Trapping was conducted in New England, OH, MI, IN, MD, WV, and PA, and some aerial surveys were done in NY. Also, they supported some activity in southern states. Some states left pine shoot beetle traps out and switched lures in early summer. Marla Downing (USFS FHTET) provided *Sirex* risk maps to the states to help guide the trapping efforts. Intercept panel and Lindgren traps were used in the surveys. Proposed for 2007 survey is an expanded trapping area in the Midwest and mid-Atlantic area. They would like to incorporate trap trees into the program both for survey and for possible nematode release. Noel's priorities are: evaluate biocontrol efficacy and impacts on non-targets, develop improved survey tools, and assess ecological and economic impacts.

Peter de Groot – Presented the Canadian update. Canadian Food Inspection Agency in 2005 found *Sirex* in bark beetle traps from Cambridge (W. of Niagara) to Oxbridge, which is in Southern Ottawa along the St. Lawrence Seaway. In 2006, they targeted their survey and looked for unmanaged overstocked plantations especially of Scots pine (there are many abandoned Christmas tree plantations on private land), with visible signs of stress, and in areas near wood processing facilities or other industrial activity. They aimed for 150 sites each in Ontario and Quebec. Panel Intercept and Lindgren traps were paired at each site. They tried to get the traps 6 feet off the ground. Traps were suspended by wire strung between trees. Synergy lures were used instead of Phero Tech to maintain consistency with the U.S. Traps were serviced every 2 to 3 weeks and the lure was changed every 6 to 8 weeks. Ontario had 158 trap locations and Quebec had 56. Thirty-eight positive trap sites provided a total of 74 insects. No *Sirex* were trapped in 21 counties in Quebec and also no *S. noctilio* were captured in bark beetle traps placed in New Brunswick or Nova Scotia. After a "maybe" Ste. Sault Marie "find" that later provided negative, they set out a number of traps northeaset of Ste. Sault Marie in a large area of Jack pine. They have seen evidence of *Sirex* in Jack pine further south. In the whole survey effort, they caught a number of other *Siricid* wasps, 4 *Sirex* spp., 3 *Urocerus* species, and *Tremex* and a *Xeris* in Ontario, with similar results in Quebec.

The Hudson's Bay find from the 1840's (north of Churchill), Manitoba was reconfirmed as *S. noctilio* by N. Schiff. The reported find of *S. noctilio* from Yellowstone was reexamined and it was not *S. noctilio*.

Lynn Evans-Goldner – Discussed a proposal of quarantine that was drafted by PPQ Program Staff in the spring of 2005 and circulated to NY and PA for review. The draft document was submitted to the PPQ Policy Analysis and Regulatoy Coordination (PARC) staff, along with a draft Regulatory Workplan. A second review period by PPQ Management and, potentially impacted states, is planned. Before we will enact a quarantine, we also have to demonstrate that we have funds available or any quarantine rule that could be rescinded. For *Sirex*, it was originally assumed that a transfer of funds (emergency funds) from the Commodity Credit Corporation (CCC) was not possible since the pest can not be eradicated. Unexpectedly, in 2007, the Sirex Program was invited to submit a CCC request. In 2006, we used some user-fee funds for surveys in port areas. In 2007, we are looking for a total of about $4.2 million for operation and about $700 thousand for research. Various surveys and regulatory programs are planned for NY, PA, North Eastern area, Western Region, ports, etc. Western Region is planning for approximately $500k in surveys.

Doug Allen and Fred Hain expressed concerns that we don't have some dedicated funding that can be used to put together a comprehensive research program. Silvicultural and biological information needs to be developed for long-term management. Doug Allen said that part of the frustration in NY is from landowners, etc. who say we are doing a lot of surveys to tell them they've got a problem, but not doing anything to actually help them with the problems. Hain suggests a "big bug" approach that was used in the 1970's for this and similar problems. Several comments also suggested that we need to work harder to gain support from industry, etc.

Bernard Slippers – Presented information on *Sirex noctilio* in South Africa. Originally it was discovered in the Cape Town area. This area doesn't have a lot of pine and there are some large gaps between stands of pine. *Sirex* is creeping around the coast to eastern areas where there are larger pine growing areas. Emergence is mostly in December through April in the Cape Town area, but peaks in October through mid-November in more Eastern areas. They don't know why the differences in emergence patterns occur, but it is expected to be related to the diffence in weather. There are high density plantation stands of *Pinus patula* in the northeastern portion of the country. There are differences in rainfall patterns; in the East, it is predominantly in the summer, and in the Cape Town area, predominantly in the winter.

The nematode parasite, *Beddingia siricidicola* was introduced soon after *Sirex* was introduced in the mid 1990's. The program seemed to work within plantations well, but the program was dropped because *Sirex* populations were low in the area and they didn't think it would get to the major plantations in the East. When it was later found in the East, the nematode was introduced in large numbers (2005), but they got very low parasitism rates. Only a few (< 5%) of the wasps emerging out the logs were infected. The next year (2006), they tried again and they are trying to be more careful with the application techniques, etc., but infection rates were low again for some unknown reason (but a little bit higher, about 5%). In *Pinus radiata*, we'd expect > 95% parasitism in a similar situation. This is causing great concern, within the industry and the program. *Sirex* wasps emerging later in the season did seem to have higher parasitism rates, also wasps from the lower portions of trees had higher parasitism. Most wasps, however, emerged from the middle and top. Apparently, the water content of wood gets very low in the dry season and they are trying to determine if this is part of the problem. They are also studying loss of nematode virulence, symbiont incompatibility, the impact of the pine spp. on the nematode, and possible competition of the fungus with blue stains. Hammer quality and condition are very important in cutting trachids cleanly so nematodes can enter. They are also trying to work with the parasitoids, especially trying to increase the *Ibalia* populations.

In studies of the fungus-wasp relationship, they have found some evidence that female *Sirex* occasionally pick up sexually reproduced genotypes of the fungus. They haven't seen this in the southern hemisphere, but they have in European populations. In the Southern hemisphere, you only find clonal biotypes of the fungus. U.S. isolates are distinct from those in the Southern hemisphere, suggesting our fungus and *Sirex* likely came from Europe.

For identifying strains of the wasps, they are looking at mtDNA COX1 haplotypes. So far, it looks like the two main haplotypes in Europe are found in U.S. and S. Africa. *Sirex noctilio* in the Cape area are predominated by one, those in eastern areas of South Africa by the other. A third apparently unique haplotype has cropped up in Argentina. Early research by Bedding (1972) showed some evidence that some *Beddingia* strains are better at sterilizing some *Sirex* strains than others.

An international *Sirex* workshop will be held on May 10-16, 2006 in Pretoria. Participants will visit Eastern areas, discuss research being done in various areas of the world, and visit areas of the main infestations.

Robin Bedding – Added that the Australians are worried about 200,000 acres in northwestern Australia, which is relatively isolated from other pine areas. Forest managers have ignored what they've been told about *Sirex* and currently they are up to 5% infestation. This could be up to 30% next year if previous patterns hold. He also added that the nematode is not so specific in relation to insect species, but is extremely specific to the *Amylostereum areolatum* fungus and has to go through the fungus to complete its life cycle.

Kevin Dodds – Presented preliminary results of the field trials conducted jointly between the Otis PSDE Laboratory and his group. Generally, too few *Sirex* we caught to do serious statistical comparisons. They studied how capture at trap trees was affected by the timing of chemical girdling in 3 species of pine at 3 times. *Sirex noctilio* seemed to have more attacks on Scots pine, but Scots also has more pronounced symptoms than either red or white. There is a lot of evidence of different species of insects in the wood and evidence of various blue stains. A portion of treatment trees will be dissected and a portion will be held for emergence of all insects. Infection rates of *S. noctilio* females will be studied.

Trap design study – did not find any significant difference related to trap design, but the Lindgren, intercept panel trap and cross-vane all look similar. In the semiochemical study, also very low numbers were captured. Generally, trap trees caught more than baited traps. The alpha beta 30:70 blend of pinene seemed to capture a few more than other lure treatments, but no statistics have been run. The log study is similar in that there was not any statistical resolution, but 2- to 4-week-old logs caught the most *Sirex*. This is similar to results reported in the literature.

In general observations, suppressed trees seem to be hit harder than dominant/co-dominant trees. They want to look more at using bark beetle aggeration phermones and anti-attractants to protect trap trees from becoming infested by scolytids, trap tree method development and optimual lure studies. Also, the Forest Service is doing a replicated thinning study. Richard Reardon is planning to look at parasitoid biology in Ft. Drum, NY.

Peter de Groot – Also presented a research update for Canada. They compared PheroTech *Sirex* lure, *Sirex* and ethanol, ethanol alone (ca. 1.2 g/d) and blank in one test and in another they compared, alpha-pinene, beta-pinene, both alpha and beta, and a blank. In both tests, they used the APT intercept panel traps.

As Kevin Dodds et al. mentioned, they also noted other woodborers and other fungi in *Sirex*-infested trees and are interested in competition effects. Specifically, they noted a lot of the blue-stain, *Monochamus* and scolytid attacks on *Sirex* trees and captured many scolytids in traps.

They are up to 38 infested stands that they are aware of in Ontario. They want to use at least some of these as long-term study sites to see what role *Sirex* plays in the ecology there. They have Scots, jack, and eastern white pines and probably others (Jack pine) in various areas.

Jim Tumlinson/Katalin Boeroeczky/Damon Crook/Joe Francese – [Tumlinson reporting:] – Started looking for *Sirex* attractants a year before the infestation was found in NY. They reported that working with Damon and Joe they have found a contact pheromone involved in mating. They also have been looking for differences in healthy vs. stressed trees and are trying to identify chemical differences. Damon has been running the GC-EAD. Laboratory/field bioassays are difficult. Katalin is looking at pine volatiles emitted by stressed vs. non-stressed pines and needles vs. trunk volatiles. They have collected volatiles through daylight hours. Jim said that in Brazil *Sirex* adults seemed to be active through the day. To collect volatiles, they are using push/pull pumping system with Teflon bagging. [Katalin reporting:] In treated (Banvel injected) red pine trees, alpha and beta-pinene were higher than normal. Katalin also pointed out that δ-3-carene production appeared to be associated only with stressed trees. On Scots pine, δ-3-carene production was more variable, perhaps because some trees were already stressed. They also sampled some needles on "near-dead" trees at one site; again they found δ-3-carene in sicker trees, plus some needle-specific compounds.

Nathan Schiff/Fred Hain – Suggests that Schiff, with more specimens could gain insight on whether it was one or multiple introductions. Bernard and Nathan think fungal clones may provide more telling information at this point than analysis of *S. noctilio* specimens. For this purpose, *Amylostereum* should be isolated from wasp mycangia, or wasps stored in alcohol for DNA analysis (of both the wasp and fungus). Isolations directly from *Sirex* infested wood (around or close to wasp galaries) will serve the same purpose.

Dave Williams – Described his inoculation of 96 trees in NY a little over a month earlier. He also reported that the Australian strain of the fungus appears to be faster growing then the strain we have in North America, perhaps raising some concerns about releasing a second strain of fungus. In culture of the nematodes, the "North American" strain of the fungus can be used so that only it is released.

Bernard Slippers – Suggested that we should survey for fruiting bodies as we go along our other work. We probably have some sexual reproduction going on here. Turn over logs, the fruiting bodies look like pieces of leather on the bark. The color can be quite variable. If we find it, cut a chunk of wood with it to aid in the identification, as fruiting bodies are very difficult to identify. If you find one, a piece can be suspended from the top of the Petri dish over agar and the spores will inoculate the plate.

Findings and Recommendations

Survey

The *Sirex* SP believes that in large part, the 2006 systematic survey accomplished its goal of delimiting. The western edge, however, is not clearly defined because of the proximity of positive finds in Canada near the border with Michigan. In addition, the northern part of Ontario was trapped late in the season, probably after peak flight, so the distribution there is unknown. Also, negative results are not definitive because of the large distance between traps and low efficiency of the trap.

The science panel suggests that additional delimitation trapping be carried out in 2007 to track the current distribution and future movement of *Sirex* populations and to stage the resources for implementing control and regulatory programs. Experience has shown that *Sirex*, when invading new areas, moves approximately 25 miles per year. This, coupled with the low efficiency/effectiveness of traps used in the 2006 survey, suggests that the outer extent of infestation is currently poorly defined and will probably move rapidly. The SSP recommends that the program survey in a band that extends 100 miles beyond the currently known infested counties. If resources permit, the outer 50 miles of this band should be trapped with semio-chemical baited (a recommendation to follow pending results from S. Africa and Chile testing) traps at a rate of one trap per 25 $mi.^2$ (5 x 5 mi. cells). In the 50-mile band that is adjacent to the infested area, the programs should utilize groups of trap trees (5 to 10/group) on roughly the same grid pattern (1 group/25 $mi.^2$). This-trap tree group (TTG) should be established in plantings of, in order of preference, stressed Scotch and red pine. Cells where no Scotch or red pines are available should be skipped. A detail trap-tree protocol should be prepared for operational users.

The band of trap trees will provide for a more effective survey than semio-chemical baited traps and, when trees are positive for *Sirex noctilio*, provide a source of infested trees for nematode (*B. siricidicola*) release. It should be noted that, although trap trees may provide a more effective survey, the logistics and activities will be different than trapping. In the spring, prior to adult flight, stands of high risk pines will have to be located and groups of trees girdled (chemically or mechanically). In late summer, these trees will need to be felled and checked for the presence of *Sirex* by checking for resin beads and by peeling sections of trees. Where there is evidence of siricid activity, larvae should be collected and preserved.

To provide additional sites for *B. siricidicola* release and better define the extent of the infestation, a second 50-mile-wide band of trap trees should be established inside and adjacent to the outer band of trap trees. If resources are not adequate to establish this 100-mile wide band of trap trees (50 + 50) around the infestation, the SSP recommends that it be 50 miles wide with 25 miles outside and 25 miles inside of the "smoothed" line along the outer (western, southern, and eastern) edges of the infested counties (positive trap counties in 2006). The 25-mile area (25-50 miles outside of the infested county line) that would not have trap trees would be trapped with semiochemical bait traps.

Control

The science panel in 2006 recommended that a biocontrol program based on release of the nematode be established and this remains the SSP opinion. A white paper (appendix to this document) addressed some of the concerns that have been expressed about the introduction of this biocontrol organism. The recommendation is to use the trap tree survey, described above, to facilitate this release. If all permits are not in place for going forward with a release of the nematode, then traps can be substituted for the groups of trap trees. If the program does implement a nematode release program and does not use trap trees, then the priority should be those positive naturally infested sites outside and just inside of the known infested county line.

If the resources for establishing trap trees and/or the number of nematodes are a limiting factor, then the highest priority should be along the southern edge of the infestation followed by the western and then the eastern edge. The lowest priority for establishing trap trees and release should be in the center of the infested area. If resources are adequate, nematode release can be made on naturally struck trees in this central core.

Regulatory

The SSP strongly recommends the regulations that control the movement of high risk commodities be established as soon as possible. Delays in regulating these commodities greatly increase the probability of artificial movement, which will contribute to rapid movement and the resulting damage. Also, if a larger area is involved at this juncture, it will only confound the logistics, cost and possible success of any control program mounted. Details on how best to apply a biological program in North America are unknown. Variables, such as climate, tree species, and competing organisms all may factor into the development of a successful program. In addition, many aspects of the insect biology and behavior its fungal symbiont, natural enemies, and North American hosts are unknown. Until the "North American" *Sirex* systems are better understood, an operational program will struggle to function successfully.

High risk items should be immediately regulated. These include all untreated round wood, such as poles, posts, log home components, pulpwood, firewood, etc. Green pine lumber is also of concern, and articles made from it also provide high-risk pathways. Chips are a potential risk item, and research is needed to determine what size chips are safe for movement. Movement of pine nursery stock should be evaluated for risk. Movement of pine nursery stock should also be evaluated for risk. Green limbs for wreathes and decoration are of less concern. In a number of cases, the SSP believes producers can develop safe-movement protocols for low-risk times of the year. All counties where *Sirex noctilio* has been trapped or where life stages have been found should be regulated. In addition, a buffer to provide for natural dispersal and the imprecision of our current survey should be factored in. The SSP recommends that the buffer should be 50 miles or one county, whichever is more practical to regulate.

Research

A number of items were covered by the first SSP report, and all remain as research priorities (see Appendix 3). The following list reinforces specific earlier recommendations and adds a few new ones.

1. Given results of Dicamba tree-girdling studies this year, additional studies of application rates, alternative chemicals and mechanical girdling should be undertaken.
2. Describe the ability of *B. siricidicola* to move and reproduce within the vascular system of North American pine species.
3. Characterize the North American strain(s) of the fungal symbiont, *A. areolatum*.
4. Determine the optimal number of trap trees to deploy at each trap-tree survey site.
5. Determine the optimal number of traps per survey site.
6. Continue to develop semiochemical lures for *Sirex*.
7. Characterize the nematode strain(s) already present in North America.
8. Evaluate the impact of cold winters on the nematode-fungus-*Sirex* complex.
9. Develop degree-day model for *Sirex* development and nematode development.
10. Evaluate interactions of *B. siricidicola* with other species of nematodes.
11. Evaluate infection rates of other species of nematodes on *S. noctilio*.
12. Characterize the impact of *Sirex* on stands of pine and evaluate silvicultural practices.
13. Develop chemical (e.g. serological) methods that can be used by field personnel to identify various life-stages of siricid wasps and their associated fungi to species.

Science Panel
Answers to Specific Sets of Questions

1. ***What determines the time of emergence of Sirex****?* At present, we aren't sure exactly what factors determine timing of emergence, but the experience in South Africa suggests that more than simple temperature accumulation may be involved (esp. rainfall patterns/wood moisture). This is a potential subject for study and model development.
2. ***How far will Sirex fly in a year?*** According to Robin Bedding, flight mill studies indicate that it has a very long-range flight potential (> 150 km or more). Field experience indicates that populations can and will spread (apparently by natural dispersal) 25 to 30 miles per year.
3. ***Rates of parasitism in New York?*** Our best estimate at present is around 10% overall.
4. ***What is the origin of the introduction?*** Probably European based on Bernard Slippers' analysis of our fungal strain.
5. ***What lure should be used in 2007?*** We want to see results of ongoing tests in Chile and S. Africa before coming up with a definitive answer.
6. **What trap?** Currently, a Lindgren, Panel Intercept or cross-vane can be used.
7. ***Should we use sticky or collection traps?*** Both have advantages and disadvantages.
8. ***Does a female in a trap mean that county is infested?*** Yes, the SSP believes that if a female was captured that it represents a reproducing population.
9. ***Wood or bark chips may need to be regulated?*** At this point, we should not move wood chips greater than 1 inch in (2 directions) unless research demonstrates that wood chipped to a larger specific size will provide quarantine security. Bark chips are less of an issue than wood chips for this insect and do not need to be regulated.
10. ***What is the next step if B. siricidicola doesn't survive NY winters?*** If the nematode doesn't survive NY winters, then the program will have to reevaluate its direction, but the nematode was originally collected in Eastern Europe where the winters are cold. If the operational strain is found to lack cold tolerance, then we may have to collect and evaluate "new" strains from Europe.
11. ***What about biological control (other than nematode, we're assuming) of Sirex in N.A.?*** The impact of North American parasites should be characterized. It should be noted that the parasitoid spp. that were used most successfully in Australia were actually North American species and are already being recovered from *Sirex* here.
12. ***Is B. siricidicola present in NY?*** We don't know for sure, but we are trying diligently to find out.
13. ***Would the nematode be successful in an area with low Sirex populations?*** Probably, it is ideal to get it established before 5% of the trees have been struck when the population is at early stage in its cycle. However, you need enough *Sirex* to "hit" trees before you release the nematodes, hence, the use of trap trees.
14. ***Would removing decadent Scots pine on public lands be an effective strategy to reduce S. noctilio populations in NY?*** Good silvicultural practices in stands of Scots and other pines would benefit management of *Sirex* populations, but these need to be practiced on an area-wide approach. A property-by-property approach would have minimal impact.
15. ***What treatment other than temperature could eliminate S. noctilio from wood > 6" in diameter?*** We will likely be able to include pressure treatment with arsenical-like compounds as a viable treatment. We are also testing fumigants, RF microwaves, etc. Some items may also be able to be moved safely if the end use and timing of movement are regulated.

WHITE PAPER

Potential non-target effects of *Beddingia siricidicola* when used as a biological control agent of *Sirex noctilio* in North America

D. W. Williams — USDA, APHIS, Otis ANGB, MA — 25 January 2007

Introduction

Sirex noctilio was identified in pheromone trap collections in Oswego County, New York, in the fall of 2004. It apparently was introduced into North America in recent years but may have been here longer (Benson 1943). This exotic woodwasp does not seem to be under natural control, is spreading rapidly, and poses a serious threat to pine forests and plantations in North America if not controlled. Its most effective natural enemy, the entomopathogenic nematode, *Beddingia siricidicola* (Bedding) (previously known as *Deladenus siricidicola* Bedding), has been used successfully as a biological control agent in management programs in Australia, New Zealand, and South America (Bedding & Akhurst 1974, Bedding 1993, Bedding & Iede 2005). The current biological control program in Australia uses the Kamona strain of *B. siricidicola,* which was selected for its high infectivity. Pending approval for environmental release, this strain will be used in the Sirex management program in the United States (Bedding & Iede 2005).

Evaluating potential risks of using *B. siricidicola* as a biological control agent of *S. noctilio* requires an understanding of the four-species community of which the nematode is a part. *Sirex noctilio* and its fungal symbiont, *Amylostereum areolatum* (Fries) Boidin, are coevolved to gain entry to the woody tissue of pine species and exploit it as a resource. *Sirex noctilio* females carry arthrospores or oidia of *A. areolatum* in a specialized mycangial organ and inject them into wood through the act of drilling with the ovipositor. In addition to fungus, a female injects toxic mucus and, if the tree is suitable, an egg. The mucus makes the tree susceptible to *A. areolatum,* which easily invades the vascular system of a tree and kills it. The fungus breaks down cellulose to provide food for developing *S. noctilio* larvae that mine the fungus-permeated wood.

In nature, *B. siricidicola* exploits each of the symbionts to different ends—the fungus as a food resource and Sirex as a means of dispersal. In the absence of Sirex larvae, nematodes grow and reproduce on the fungal hyphae inside a single tree, developing in a distinctive "mycetophagous" phenotype (Bedding 1972). When in proximity to a Sirex larva, a juvenile nematode develops into a morphologically different "entomopathogenic" phenotype. This parasitic form has a large stylet, which it uses to puncture the larval cuticle. Female nematodes reproduce inside a host pupa, which eventually develops into a female or male wasp that is fully functional except that it is sterile. Juvenile nematodes replace the egg contents in adult females, and on emergence, parasitized Sirex females oviposit as usual but lay eggs filled with nematode juveniles instead of normal eggs.

Consideration of any non-target effects of *B. siricidicola* must evaluate potential effects on at least three groups of insects. The first group comprises other siricid species, which may be affected by *B. siricidicola* in the same way as *S. noctilio*—through attack of larvae and sterilization of adults. The second group includes several species of hymenopterous parasitoids, which are intimately associated with Sirex species inside a tree and are known to be attacked by another nematode, *Beddingia wilsoni* (Bedding) but not by *B. siricidicola*. The third group is made up of all the other species, primarily Coleoptera, that belong to the community feeding in the wood of conifers. Because the system of fungus, nematode, and woodwasp involves symbiosis and specialized adaptations, the risk of parasitism by *B. siricidicola* decreases through the three groups as the species are increasingly less related ecologically.

North American siricids as potential hosts

The twenty siricid species and subspecies in North America comprise five genera: *Sirex*, *Urocerus*, *Xeris, Eriotremex, and Tremex* (Table 1). *Tremex columba* (L.) and *Eriotremex formosanus* (Matsumura) attack deciduous tree species. The remaining woodwasp species attack conifers, and all *Sirex* species as well as four *Urocerus* species attack *Pinus* species. Each species has several recorded hosts, and no species are especially rare. Unlike *S. noctilio*, none of the North American siricids attack healthy hosts; all oviposit in trees that are weakened or dying from damage caused by fire, wind, other insects, diseases, smog, or mechanical operations. They apparently are not considered to be serious forest pests (Furniss & Carolin 1977, Madden 1987), are not rare, and can be considered beneficial insects in the natural forest environment to the extent that they hasten the decomposition of dead trees.

The primary factor affecting exposure of a siricid species to *B. siricidicola* is its fungal symbiont. The two most common siricid symbionts worldwide are *A. areolatum*, which is indigenous to Europe and Japan, and *A. chailletii* (Pers. ex Fries) Boidin, which is indigenous to North America, Europe, and Japan. *Beddingia siricidicola* feeds only on *A. areolatum* (Bedding & Akhurst 1978). Thus, siricid species that feed on *A. chailletii*, including most of those in North America (Table 1), will not encounter *B. siricidicola*.

Only a few North American siricid species potentially may feed on wood colonized by *A. areolatum*. In particular, *Xeris* species are not symbiotic with any fungus species, but instead, oviposit in trees already attacked by another siricid species and inoculated with its fungus (Stillwell 1966, Fukuda & Hijii 1997). The subspecies, *X. morrisoni indecisus* (MacGillivray), *X. spectrum spectrum* (L.) (which also occurs widely in Eurasia), and *X. spectrum townesi* Maa, will all be exposed to *B. siricidicola* (i.e., if it is released) as *A. areolatum* spreads across North America with the dispersal of *S. noctilio,* but only if and when these woodwasps attack trees already infested with *S. noctilio*. Alternatively, the North American *Xeris* species did not evolve with *A. areolatum* as did *Xeris spectrum* populations in Eurasia. Thus, it is by no means certain that any of the native *Xeris* populations will be able to use *A. areolatum* or will be attracted to it in the same way.

In addition, two *Sirex* species, *S. juvencus juvencus* (L.) and *S. cyaneus* F., may be attacked by *B. siricidicola*. Both species are Holarctic in distribution, and presumably both are symbiotic with

A. areolatum in the Palaearctic Region and *A. chailletii* in the Nearctic Region. Because these species are capable of symbiosis with the two *Amylostereum* species, it is theoretically possible (albeit not demonstrated) that they may adapt in North America to use the introduced *A. areolatum* as a resource, exposing them to attack by *B. siricidicola.* As an aside, it must be noted that the endemism of *S. juvencus juvencus* in North America is questionable; the subspecies is suggested to have been introduced from Europe (Morgan 1968). Conversely, *S. cyaneus* is thought to have originated in the Nearctic and been introduced into Europe. In summary, at most, three *Xeris* subspecies and two *Sirex* species may potentially be exposed to *B. siricidicola* if it is released as a biological control agent.

Hymenopterous parasitoids as potential hosts

Considerable information on the hymenopterous parasitoids of Sirex and their relationships with *Beddingia* species is available because of the biological control campaign mounted in Australia during the 1960s in which extensive explorations were conducted throughout the world (Cameron 1965, Taylor 1976, Spradbery & Kirk 1978, Madden 1987). In the course of that campaign, 21 parasitoid species were imported into Australia, 10 of which were released and 5 of which became established: *Ibalia leucospoides* (Hockworth), *Ibalia ensiger* Norton, *Rhyssa hoferi* Rohwer, *Rhyssa persuasoria* (L.), and *Megarhyssa nortoni* (Cresson). All five species occur in North America, and some of the colonization stock in Australia originated here. All species except *R. hoferi* are reported to attack one or more indigenous North American siricid species (Cameron 1965). The ichneumonids, *Rhyssa* spp. and *Megarhyssa nortoni*, are parasitized by *Beddingia wilsoni*, a native North American nematode. However, successful parasitism by *B. siricidicola* does not occur (Bedding 1968, Bedding & Akhurst 1978), and it seems unlikely that any North American ichneumonid species will be affected directly by biological control releases of this exotic nematode.

Other wood dwelling insects as potential hosts

Only one other insect species—the only one not a Hymenoptera—has been cited as attacked by *B. siricidicola*. Bedding and Akhurst (1978) reported that "both *D. wilsoni* and *D. siricidicola* have been found producing juveniles in *Serropalpus barbatus* (Schaller), a beetle commonly associated with siricids." This melandryid beetle is distributed widely across Europe, Siberia, and northeastern North America (Baker 1972, Kolk & Starzyk 1996). Its hosts are common fir and Norway spruce, and although common, *S. barbatus* is not considered a serious timber pest. Bedding and Akhurst (1978) did not indicate whether nematode parasitism sterilizes the beetle or allows it to continue development, potentially providing another pathway for the dispersal of *B. siricidicola*.

Questions on non-target effects on North American siricids

There are two main questions related to non-target effects of a biological control program using *B. siricidicola*. First, what siricid species will be exposed to attack by the nematode? And second, how great are impacts likely to be on North American woodwasp populations that are capable of being parasitized?

The first question has been addressed in previous paragraphs. Where they occur in the same area as *B. siricidicola,* all *Xeris* species potentially will be exposed to parasitism if they develop in pine trees containing *A. areolatum*. *Sirex juvencus juvencus* and *S. cyaneus* are much less likely to be exposed to parasitism. To do so would require that the North American populations adapt to develop on *A. areolatum*, which seems unlikely in the near future.

In general, it is important to remember that populations of the North American *Sirex, Urocerus,* and *Xeris* species feeding on pine currently develop in trees invaded by *A. chailletii.* That fungus represents a refuge from the nematode, and siricid larvae feeding in it are invulnerable to parasitism. Indeed, selective pressures imposed by the nematode on woodwasp populations shifting to *A. areolatum* should serve to maintain a strong association of North American pine-feeding siricids with *A. chailletii*.

The answer to the second question is considerably less certain. It is difficult to predict the impact of parasitism on *Xeris* populations although, of course, those populations developing on *A. chailletii* will not be affected. The cosmopolitan subspecies, *X. spectrum spectrum*, is parasitized by *B. siricidicola* in Eurasia, yet it apparently remains a common insect there. However, the natural control situation in Eurasia and a classical biological control program in North America may not be entirely comparable. The Kamona strain has been selected for high pathogenicity on *S. noctilio.* Its impact on non-target siricid species may be greater than that of naturally occurring *B. siricidicola* strains in the Palaearctic. Nevertheless, even the most successful biological control programs have not driven their target species to extinction. All in all, it seems unlikely that impacts on *Xeris* populations will be great. Ultimately, any possible negative impacts of the biological control program on North American siricids must be weighed against the costs to our forest resources if *S. noctilio* is not managed.

Acknowledgments

I thank Robin Bedding, Nathan Schiff, Bernard Slippers, and Vic Mastro for their helpful comments.

Table 1. Species of Siricidae reported from North America (Morgan 1968, Baker 1972, Furniss & Carolin 1977, Talbot 1977, Bedding & Akhurst 1978, Krombein et al. 1979, Smith & Schiff 2002, Slippers et al. 2003)

Genus	Species	Subspecies	Subfamily	Region of N. America	Host type	Attacks *Pinus*?	Fungal symbiont
Sirex	*areolatus*		Siricinae	East, West	coniferous	Yes	*A. chailletii*
Sirex	*behrensii*		Siricinae	West	coniferous	Yes	???
Sirex	*cyaneus*		Siricinae	East, West	coniferous	Yes	*A. chailletii*
Sirex	*edwardsii*		Siricinae	East	coniferous	Yes	*A.chailletii*
Sirex	*juvencus*	*californicus*	Siricinae	West	coniferous	Yes	*A. chailletii*
Sirex	*juvencus*	*juvencus*	Siricinae	East, West	coniferous	Yes	*A. chailletii*
Sirex	*longicauda*		Siricinae	West	coniferous	Yes	*A. chailletii*
Sirex	*nigricornis*		Siricinae	East	coniferous	Yes	*A. chailletii*
Urocerus	*albicornis*		Siricinae	East, West	coniferous	Yes	*A. chailletii*
Urocerus	*californicus*		Siricinae	West	coniferous	Yes	*A. chailletii*
Urocerus	*cressoni*		Siricinae	East	coniferous	Yes	???
Urocerus	*gigas*	*flavicornis*	Siricinae	East, West	coniferous	Yes	*A. chailletii*
Urocerus	*taxodii*		Siricinae	East	coniferous	No	???
Xeris	*morrisoni*	*indecisus*	Siricinae	West	coniferous	Yes	none
Xeris	*morrisoni*	*morrisoni*	Siricinae	West	coniferous	No	none
Xeris	*spectrum*	*spectrum*	Siricinae	East, West	coniferous	Yes	none
Xeris	*spectrum*	*townesi*	Siricinae	West	coniferous	Yes	none
Xeris	*tarsalis*		Siricinae	West	coniferous	No	none
Eriotremex	*formosanus*		Tremicinae	SE U.S.	deciduous	No	*???*
Tremex	*columba*		Tremicinae	East, West	deciduous	No	*Cerrena unicolor*

References

Baker, W.L. 1972. Eastern Forest Insects. USDA Forest Service, Misc. Publ. No. 1175.

Bedding, R.A. 1968. *Deladenus wilsoni* n. sp. and *D. siricidicola* n. sp., entomophagous-mycetophagous nematodes parasitic in siricid woodwasps. Nematologica 14: 515-525.

Bedding, R.A. 1972. Biology of *Deladenus siricidicola*, an entomophagous-mycetophagous nematode parasitic in siricid woodwasps. Nematologica 18: 482-493.

Bedding, R.A. 1993. Biological control of *Sirex noctilio* using the nematode *Deladenus siricidicola*. *In* Nematodes and the biological control of insect pests, pp. 11-20, ed. R.A. Bedding, R.J. Akhurst & H.K. Kaya. CSIRO Publications, Australia.

Bedding, R.A. & R.J. Akhurst. 1974. Use of the nematode *Deladenus siricidicola* in the biological control of *Sirex noctilio* in Australia. J. Austr. Entomol. Soc. 13: 129-135.

Bedding, R.A. & R.J. Akhurst. 1978. Geographical distribution and host preferences of *Deladenus* species parasitic in siricid woodwasps and associated hymenopterous parasitoids. Nematologica 24: 286-294.

Bedding, R.A. & E.T. Iede. 2005. Application of *Beddingia siricidicola* for Sirex woodwasp control. *In* Nematodes as Biocontrol Agents, pp. 385-399, ed. P.S. Grewal, R.-U. Ehlers & D.I. Shapiro-Ilan. CABI International.

Benson, R.B. 1943. Studies in Siricidae, especially of Europe and Southern Asia. Bull. Entomol. Res. 34: 27-51.

Cameron, E.A. 1965. The Siricinae and their parasites. Comm. Inst. Biol. Contr. Tech. Bull. 5, 31 pp.

Fukuda, H. & N. Hijii. 1997. Reproductive strategy of a woodwasp with no fungal symbionts, *Xeris spectrum*. Oecologia 112: 551-556.

Furniss, R.L. & V.M. Carolin. 1977. Western Forest Insects. USDA Forest Service, Misc. Publ. No. 1339.

Kolk, A. & J.R. Starzyk. 1996. Atlas of Forest Insect Pests. Multico Warszawa, 705 pp.

Krombein, K.V., P.D. Hurd, D.R. Smith & B.D. Burks. 1979. Catalog of Hymenoptera North of Mexico, volume 1. Smithsonian Institution Press, Washington, DC.

Madden, J.L. 1988. *Sirex* in Australasia. *In* Dynamics of Forest Insect Populations: Patterns, Causes, Implications, pp. 407-429, ed. A.A. Berryman. Plenum Press, New York.

Morgan, F.D. 1968. Bionomics of Siricidae. Ann. Rev. Entomol. 13: 239-256.

Slippers, B., T.A. Coutinho, B.D. Wingfield & M.J. Wingfield. 2003. A review of the genus *Amylostereum* and its association with woodwasps. S. Afr. J. Scis. 99: 70-74.

Smith, D.R. & N.M. Schiff. 2002. A review of the Siricid woodwasps and their Ibaliid parasitoids in the eastern United States, with emphasis on the mid-Atlantic region. Proc. Entomol. Soc. Wash. 104: 174-194.

Spradbery, J.P. & A.A. Kirk. 1978. Aspects of the ecology of siricid woodwasps in Europe, North Africa and Turkey with special reference to the biological control of *Sirex noctilio* F. in Australia. Bull. Entomol. Res. 68: 341-359.

Stillwell, M.A. 1966. Woodwasps in conifers and the associated fungus, Stereum chailletii, in Eastern Canada. Forest Science 12: 121-128.

Talbot, P.H.B. 1977. The *Sirex-Amylostereum-Pinus* association. Ann. Rev. Phytopathol. 15: 41-54.

Taylor, K.L. 1976. The introduction and establishment of insect parasitoids to control *Sirex noctilio* in Australia. Entomophaga 21: 429-440.

Sirex noctilio Science Panel December 14-15, 2006 Hyatt Regency Indianapolis, Indiana USA "Questions submitted by *Sirex* Management Team for Consideration by the *Sirex* Science Panel"					
Topic	**Question**	**Response**	**References**	**Research Underway**	**Experts**
General	Who are the members of the Sirex Science Panel (SSP) (if different than January 2006 panel members)	Add appendix with list of names, affiliation, contact information, and CV of new members.	The list exists, as well as the CV's. Information Specialist are called as needed.		
Pest Biology	What should be the peak months of *Sirex* flight in Michigan? Peak months are defined as period of time when 90% of the insects will be flying.		See response #1		
Pest Biology	What benefit would there be to keeping traps out for five months if, for the sake of argument, 90% of the wasps will be flying for a three month period? (Current USDA protocol recommends that traps be placed in the field for 5 months).	Sirex can emerge any time of the year given warm weather. We do not have a phenology model for North America so we can not predict when peak emergence will be. Once the flight period is known, the monitoring period can be adjusted accordingly.			

Topic	Question	Response	References	Research Underway	Experts
Pest Biology	How far will this wasp really fly (outside) in a year? We've heard 50 to 150 miles. Is this accurate?	No one knows precisely how far the wood wasp will fly. Information indicates it can move 25 to 30 miles or 40 to 48km on its own (see response 2).			
Pest Biology	What are current rates of nematode parasitism in North American populations of *S. noctilio*? Which species of nematode(s) are affecting them in NA?	<10% -- We do not know what species of nematode is involved yet, but we are diligently working on it (see response 12).			
Pest Biology	What is the origin of the introduction of *S. noctilio* into New York State? Can genetic analysis of the associated fungus and/or the insect pest elucidate its origin?	The fungal strain appears to be of the European origin (see response 4). B. Slippers			
Pest Survey/Detection	What is the recommendation of the SSP as to the lure that should be used in the 2007 survey.	- Awaiting data from S. Africa and Argentina (see response 5).	Vic Mastro mentioned in an email that a change in lure may be recommended based on test results.		
Pest Survey/Detection	What is the recommendation of the SSP as to the trap that should be used in the 2007 survey.	See above (see response 6). Trap trees within the boundary of the known infestation. Beyond that, the extended cross vein Lindgren or Panel Intercept.			

Topic	Question	Response	References	Research Underway	Experts
Pest Survey/Detection	What recommendations does the Science Panel have for a 2007 US *Sirex* survey plan?	- Survey along the leading edge and out to 50 miles should be conducted with trap trees. - The rate should be dependent on host tree density, but use a 1/25 mi.^{2} grid arranged (see response 6 and the body of the S.P.'s report).			
Pest Survey/Detection	If test results do not point to an improved trap design, will trap trees and /or sticky intercept traps be recommended to the *Sirex* Management Team over Lindgrens for 2007?	- Trap trees should be the option where we anticipate releasing the nematode. We will provide information on traps by early February.	Please see the body of the report.		
Pest Detection/Survey	What lure improvements if any have been made over the current alpha/Beta pinene?	See above			
Pest Detection/Survey	If only one female has been trapped in a county, does that necessarily mean the there is an infestation in the county?	Positively – Our current traps and trap trees are very effective. Trap trees also may be less efficient in areas where there are large quantities of stressed pines. Consideration should be given to using more traps or trap trees to make determinations of presence/ absence more rapid when this information is critical.	See response 8.		

Topic	Question	Response	References	Research Underway	Experts
Pest Risk/Regulatory	USDA currently regulates the movement of the following: uncomposted ash wood chips for EAB; any host commodity ½ inch or greater for ALB; and pine bark nuggets (including bark chips) for PSB. Based on pest risk, should all sizes of pine wood chips that originate from within a *S. noctilio*-infested or regulated area be allowed to move to a non-infested area or non-regulated area?	Wood chips 1" in 2" in dimension probably poses little risk of artificial Sirex movement, however, the critical experiments have not been carried out.	No. Research is needed to determine survival in different size chips generated using different processes (see response 9).		
Biological Control	What are next steps for biological control program if BC nematode does not survive NY winter?		See response 10.		
Biological Control	Is *Beddingia siricidicola* present within the *S. noctilio* population in NY?	Unknown at this point.	See response 12.		
Biological Control	What backup plans for control are available if the *Sirex* nematode does not over winter in NY?		See response 11.		

Topic	Question	Response	References	Research Underway	Experts
Biological Control	What progress has been made with respect to investigating biological control agents, other than *B. siricidicola,* in the US?	We have identified what is attacking S. noctilio. Given enough resources, we can better characterize the impact of the native natural enemies.	See response 11.		
Biological Control	Would introduction of the BC nematode be successful, if you have a very low level of *S. noctilio* infestation in a given area?	Yes, the idea is to introduce it before S. noctilio infestations build to high levels.	Establish trap trees. See response 13.		
Biological Control/Non-target Effects	Could our native, *Sirex cyaneus* (the blue horntail), and the introduced *S. juvencus*, which use *Amylostereum areolatum* in Europe, and siricids in the genus *Xeris*, which use the fungi of other horntails, be negatively impacted (or extirpated) by *Beddingia siricidicola*?		See attached white paper.		
Biological Control/Non-target Effects	Could *B. siricidicola* parasitize siricids associated with *Amylostereum chaillettii* if they inhabit the same tree as *Sirex noctilio*?	See above			

Topic	Question	Response	References	Research Underway	Experts
Biological Control/Non-target Effects	If native siricids are found to be negatively impacted by *Beddingia siricidicola,* what backup plans are available or are in development to address the control/containment of *S. noctilio* in Northeastern US?	Silvicultural controls have worked in overseas populations, except in times of tree stress. North American parasites, along with silvicultural controls may be a good option, but in a complex system like North America, it is unknown.			
Siliviculture	Could removing decadent Scots pine stands (on public land) be an effective silvicultural strategy to reduce *S. noctilio* outbreaks in NA?	Improving stand conditions through an area-wide approach should greatly benefit management of Sirex populations. Removal of individual stands or trees would have little impact.	See response 14.		
Regulatory Treatment	Other than heat treatment, what treatments can be used to effectively treat and eliminate *S. noctilio* from large wood commodities (greater than or equal to 6 inches in diameter)?	Fumigation (MB) of material up to 8" in diameter. Possibly microwave radiation or radiofrequency, pressure treatment or other new innovative techniques.	See response 15.		

Topic	Question	Response	References	Research Underway	Experts
Technical Strategic Plan	A Technical Plan is needed to address short, medium, and long term goals for silviculture, biological control, and survey. What are the near term actions that need to be considered immediately and can longer term objectives be identified?	A technical plan has been drafted and circulated.			
Environmental Assessment	Please review and comment on the draft EA.		Draft EA document will be sent as soon as possible. Version 3 of the document will tentatively be ready by the time of the SSP meeting. Lynn Goldner will supply copies.		
White Paper/Non-target Effects of *B. siricidicola*	A white paper is needed to address comments/concerns that have been raised about the potential non-target effects of *B. siricidicola*. Can the *Sirex* Science Panel prepare such a paper, in preparation for the upcoming public comment period for the EA? The EA will cover potential release of the nematode.	See above. This is included in this Sirex SP.			